PROGRESS REPORT

ON THE

ONE MICRON LASER DOPPLER RADAR

CONTRACT NO: N00014-88-C-0645

PREPARED FOR:

OFFICE OF NAVAL RESEARCH

DEPARTMENT OF THE NAVY

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1.0 INTRODUCTION

This small business innovation research (SBIR) Phase I program is to conduct research on a one micron laser Doppler radar under contract #N00014-88-C-0645 from the Office of Naval Research. The assembly and test of a breadboard one micron Continuous Wave (CW) laser Doppler system has been planned under this Phase I SBIR program. This is the progress report for period 9 September 1988 thru 15 February 1989, and provides a summary of work performed under this contract. It may be noted that laser doppler system is sometimes known as laser radar, LADAR or LIDAR, thus, these three terms will be used throughout this report for the system.

Schwartz Electro-Optics, Inc. (SEO) proposed this program with a one micron CW single frequency neodymium doped yttrium aluminum garnet (Nd:YAG) laser developed under a completed SDI Phase I SBIR contract (ref. 1). Originally, it was envision that two lasers would be required to characterize the system components, and the frequency offsets between the two lasers would be necessary for Doppler radar simulation. However, as the system hardware was fabricated and assembled it became apparent that the second laser would not be available for the program in a timely fashion. Therefore, it was decided that the system components could be characterized using a single laser in homodyne mode of operation by splitting its beam into two using a beam splitter (ref. 2).

The primary objectives of this Phase I SBIR program is outlined as follows:

1) utilize already developed diode pumped tunable single frequency Nd:YAG laser in a laser radar configuration, and
2) demonstrate its operation with moving (Doppler) targets.

These primary objectives of the program will be met with the approach described in this progress report.

After the characteristics of the components are obtained, the secondary objectives of the program will be accomplished, as listed below:

1) scientists and engineers working on SDI programs will be contacted to evaluate applications for one micron LADAR,
2) a mission scenario for the this one micron laser radar will be developed,
3) a concept for a compact solid state LADAR will be developed and proposed for a Phase II program.

1-1 SUMMARY

SEO has completed the design, fabrication and test of the optical, mechanical, and electronic hardware components required for the Phase I, One Micron Laser Doppler Radar program. The integration of these components into a laser Doppler system will be completed in February 1989 and testing in March 1989. The detailed schedule is provided in section 3.2 of this report.

The laser developed under a completed SDI program was repackaged for this program. The details of this diode pumped tunable single frequency ring laser are provided in section 2.1. The laser including a DC power supply for the pump diode and a power supply for the piezo-electric transducer (PZT) driver were delivered to Autonomous Technology Corp. (ATC), SEO subcontractor. The laser will be integrated with the LADAR transceiver breadboard and receiver electronics at ATC.

ATC has completed the LADAR transceiver breadboard opto-mechanical subassembly design, and fabrication. The optical elements required for this assembly include mirrors, waveplates, polarizing cubes, wide band detector and lenses. All these components with the exception of the lenses were received and installed in a compact interferometer (CI) developed for this program. A brief description of the CI is provided in section 2-2.

The breadboard Doppler receiver electronics design, and fabrication was completed. A frequency discriminator developed for the receiver electronics has a maximum sensitivity of 10 volts/10 MHz. A digital/audio tape (DAT) recorder will provide high performance data acquisition. The 20 kHz audio bandwidth (>40 kHz A/D) and 14 bits of low noise, wide dynamic range will be used to record the output of a velocity discriminator. This will result in a 20 kHz slew rate with wide response to small Doppler changes and provide a means of accurate post-experiment digital analysis. A brief description of the breadboard Doppler receiver electronics is given in section 2-3.

It may be noted that originally the Doppler frequency shift measurements were planned with two lasers using a frequency offset in a heterodyne mode of operation. All components designed and assembled are flexible and can be used in the homodyne mode of operation. The experimental measurements planned using the system are discussed in section 3.0.

2.0 SYSTEM DESCRIPTION

The important components of the laser Doppler radar designed and assembled by SEO are: 1) single frequency Nd:YAG laser, 2) LADAR transceiver breadboard, 3) Doppler receiver electronics. A brief description of these components is given below.

2.1 SINGLE FREQUENCY Nd:YAG RING LASER

The single frequency Nd:YAG laser consists of a pump diode, relay optics, and resonator cavity. In this section design of the laser and the hardware fabricated are discussed.

In the application of high power, CW diode lasers to longitudinal pumping of solid state lasers, a conventional wisdom has developed concerning the pump imaging optics. There are three design strategies that are employed depending on the proximity of the pump laser to the laser rod.

1) A graded index (GRIN) lens is a very simple, low loss relay that is useful in situations where the separation between the diode laser and the rod is on the order of 1 cm (ref. 3) An appropriate GRIN lens might be a quarter pitch (at 807 nm) lens that is sandwiched between the diode laser and the rod. A lens with sufficiently short working distance can be used to underfilled the cavity mode with a collimated pump beam. This configuration seems appropriate for compact, linear resonators for which the cost of the pump laser might well exceed the sum of the remaining cost of the entire laser.

2) The other extreme in relay design is to consider the pump laser as a remote component that is coupled to the laser rod through an optical fiber. This approach has a number of desirable features and has, in fact, been employed in commercial diode pump Nd:YAG lasers (ref.4). A remote pump module greatly simplifies pump replacement and temperature stabilization. In addition fiber couple system facilitates the combination of multiple diode lasers. Multimode fibers offer the simplest path to high coupling efficiency. The primary disadvantage is the coupling loss between the diode laser and the fiber which is typically 30-50 percent. Other technical issue involve with fiber coupling is pump induced noise due to optical feedback to the diode laser. The feedback effects can often be mitigated by using techniques including wedging, tapering or lensing fiber ends, applying anti-reflection coatings, and employing

isolators.

3) A properly designed combination of two lenses separated by an anamorphic prism pair is likely to yield significantly higher coupling efficiency than any fiber couple system. The highest efficiencies reported to date for diode pumped lasers have been reported with this configuration (ref. 5). This is the type of relay employed in the laser packaged for the LIDAR experiments. A schematic of the three element relay used in the laser is presented in Figure 2-1. The ray trace method has been used to show the path of the pump beam in both the tangential and sagittal planes. The tangential plane (i.e., the plane of incidence) is often referred to as the "p-plane", and the sagittal plane (orthogonal) is referred to as "s-plane. Mode matching high power (>200 mW) CW diode laser for longitudinal laser pumping is difficult because the characteristic emission pattern is highly elliptical. Perpendicular to the plane of the junction (i.e., in the s-plane), the near field is typically about 1 micron across and the emission nearly diffraction limited. Conversely, the angular width in the plane of the junction (i.e., in the s-plane) is typically many times the diffraction limit and the emission region is at least 200 micron in size. Manufacturer typically specify the full angular width O, defined between the rays at which the intensity is one half the peak power (i.e., the FWHM angular bandwidth), in both planes.

The Spectra Diode Laboratory SDL 2420 array providing 200 mW rated power was used as a pump diode. The array size specified by manufacturer as 0.5 micron (Ws) by 50 micron (Wp) and FWHM angular bandwidth of Os = 35 degrees and Op = 10 degrees. A Nd:YAG laser rod of refractive index 1.82 was longitudinally pumped by this GaAlAs diode laser. The peak absorption coefficient near 807 nm for 1 percent Nd in YAG exceeds 8/cm and may be as high as 12/cm (ref. 6). In practice, however, the effective value, is considerably less due to the spectral distribution of the pump light. In order to obtain higher absorption coefficient, greater than 4/cm, the laser diode was maintained at a constant temperature by mounting it on a plate cooled by a refrigerated coolant.

The tradeoff between efficiency and threshold should be considered in designing diode pumped lasers. A large mode size facilitates matching the pump radiation to the cavity mode in the laser rod and thereby improves the slope efficiency of the laser. However, this done at the expense of increased threshold power. The threshold, in terms of power absorbed in the laser rod, can determined from the following equation:

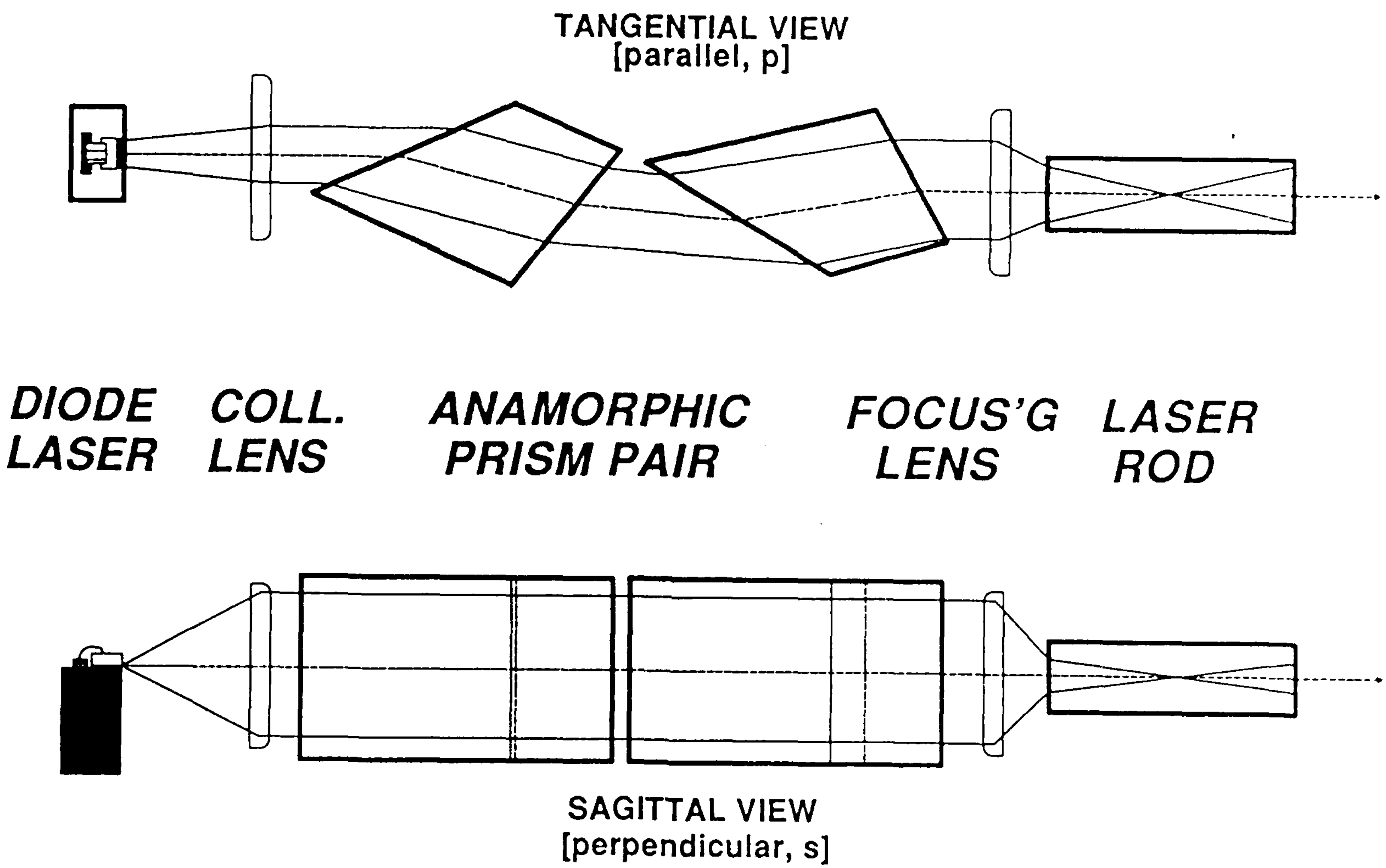


FIGURE 2-1: RAY TRACE OF THE OPTICAL RELAY

$$Pth = [(\pi h c) (L + T) (4\sigma\tau\lambda)] \{<ro^2> + <w' (z)^2>\}$$

where h is Plank's constant,
c is the vacuum speed of light,
L = 0.01, is internal cavity loss,
T = 0.02, is output coupler transmission,
σ = 5.3 x 10^{-19} /cm, is emission cross section,
τ = 230 micro-sec, is the upper state lifetime,
λ = 1064 nm, wavelength of operation.

The bracketed terms indicate that the cavity mode and pump radiation dimensions are averaged over the pumped volume. For,

$<ro^2>^{1/2}$ = 200 micron and
$<w'(z)^2>^{1/2}$ = 200 micron

he calculated absorbed threshold power is 29 mW. Assuming 86 percent of the pump light incident at the laser rod is absorbed within the mode volume, and that the transmission of the optical relay is 80 percent, the corresponding threshold power at the output of the diode laser is 42 mW and the calculated slope efficiency is 35 percent.

Figure 2-2 is a schematic of the cavity including the pump laser and relay optics. The optical components used include 6.3 mm diameter by 5 mm long laser rod, two flats coated with high reflectivity (HR) dielectric coating,and output coupler with 98 percent reflectivity with 25 cm radius of curvature (RC). The optical cavity length of 41.3 cm and the physical cavity length 40.5 cm was maintained by mounting a piezo-electric transducer (PZT) on a back of one of the HR flat shown in the figure. Thus, the longitudinal mode spacing of the cavity is 725.89 MHz. In this ring resonator, output can be obtained in either parallel or diagonal direction as shown in the figure. The laser is aligned to provide only unidirectional output .

The laser was assembled and tested for output stability. The linewidth measurements were performed using high resolution, temperature stabilized Burleigh model CFT-500 confocal etalon and scanning array attached to a computer controlled ISA HR-640 spectrometer. The experimental set up for the laser and its characteristics are discussed in section 3.0.

A photograph of the Nd:YAG laser assembled is provided in Figure 2-3. It may be noted that the photograph was taken after the laser was aligned for a unidirectional beam and enclosed in a tranperent plastic housing for stability.

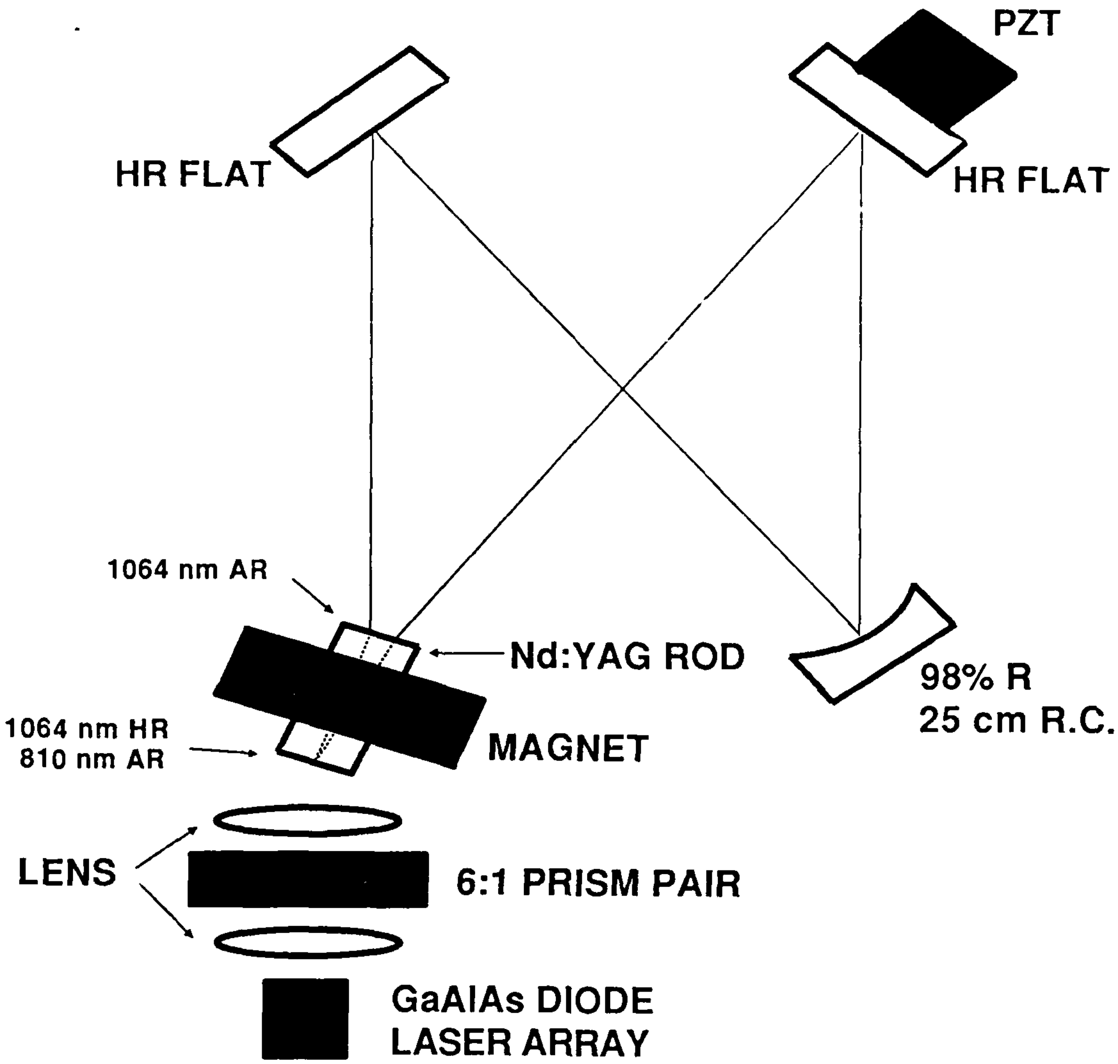


FIGURE 2-2: SINGLE FREQUENCY Nd:YAG RING LASER LAYOUT

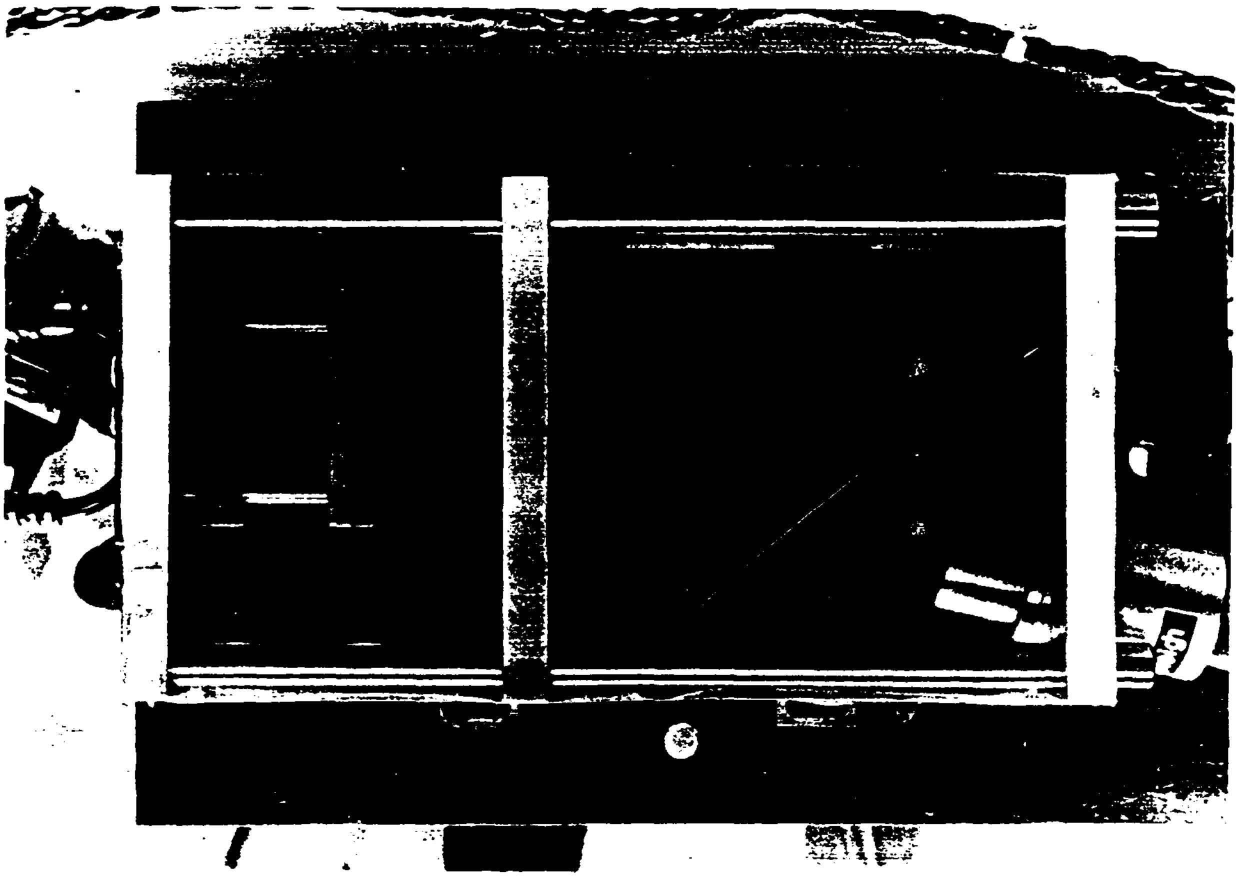


FIGURE 2-3: A PHOTOGRAPH OF THE SINGLE FREQUENCY Nd:YAG RING LASER

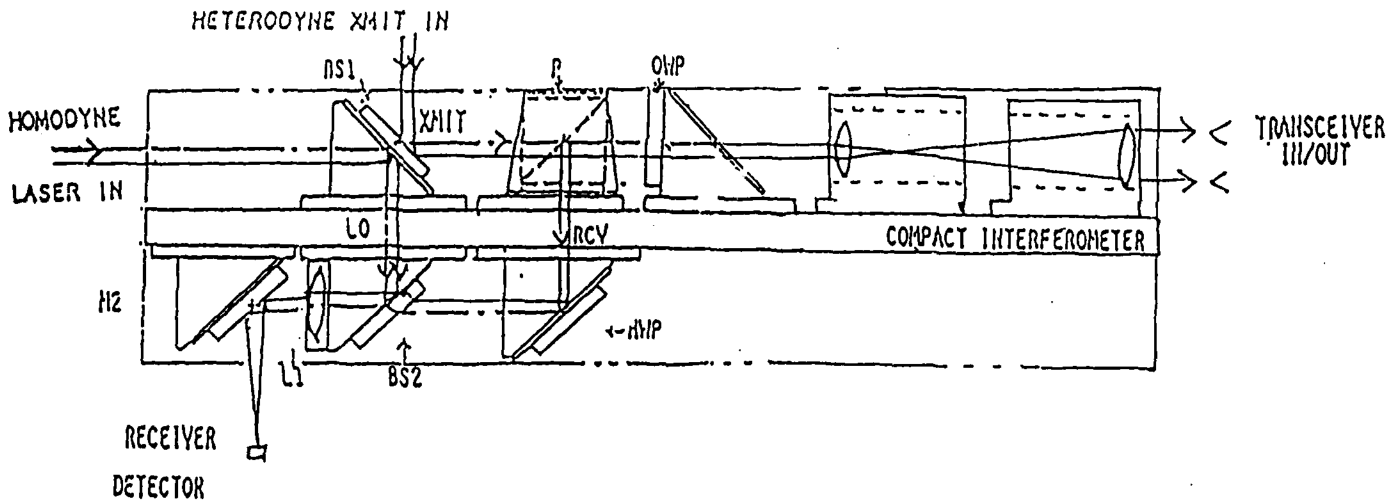
2.2 LADAR TRANSCEIVER BREADBOARD

ATC has completed LADAR transceiver breadboard opto-mechanical subassembly design and fabrication. It is a highly flexible design and it is possible to use the breadboard with simple modifications either to accept two lasers heterodyne or one laser homodyne implementation.

The approach is to collimate the diode pumped single frequency Nd:YAG laser to a small diameter beam (approximately 1.0 mm diameter). This permits short focal length optics to be used for imaging. Then, by using a beam expander on on the output transceiver beam increase in LADAR carrier-to-noise (CNR) can be obtained. The CNR for resolved targets increases by the square of the magnification.

A compact interferometer (CI) opto-mechanical package designed and fabricated is idealy suited for coherent laser radar. The CI is designed to perform the polarization duplexing function for a heterodyne and homodyne radar such that transmit and receive paths can be common. Additionally, the CI provides the spacial mixing of the received beam and local oscilltor (LO) beam. The unique characteristic of this CI is its small size. Having short optical paths wthin the critical spacial mixing optics allows mixing and duplexing before the Gaussian beam start to diverge, thus, eliminating severely alignment sensitive matching lenses. The CI will efficiently mix laser beams in the 1 mm to 6 mm 1/e^2 diameter regime.

In Figure 2-4, the layout of the optical train is shown. A photograph of the hardware is provided in Figure 2-5. The transceiver opto-mechanical unit is 80 percent completed as several optical elements (lenses) have not yet received and installed. Mirrors, waveplates, polarizing cubes and wideband detector have been received and installed.



BS1: Beamsplitter, 80% T(Xmit)/20% R(LO) for Homodyne
or Mirror, 1st and 2nd Surface Reflectors for Heterodyne
P: Polarizing Beamsplitter prism, 99% (T(P:Xmit)/99% R(S:Rcv)
QWP: Quarter wave phase retarder M1: Fold Mirror
HWP: Half wave phase retarder
BS3: 20% R(LO)/80% T(Receive beam). L1: Focusing Lens

FIGURE 2.4: LADAR TRANSCEIVER LAYOUT

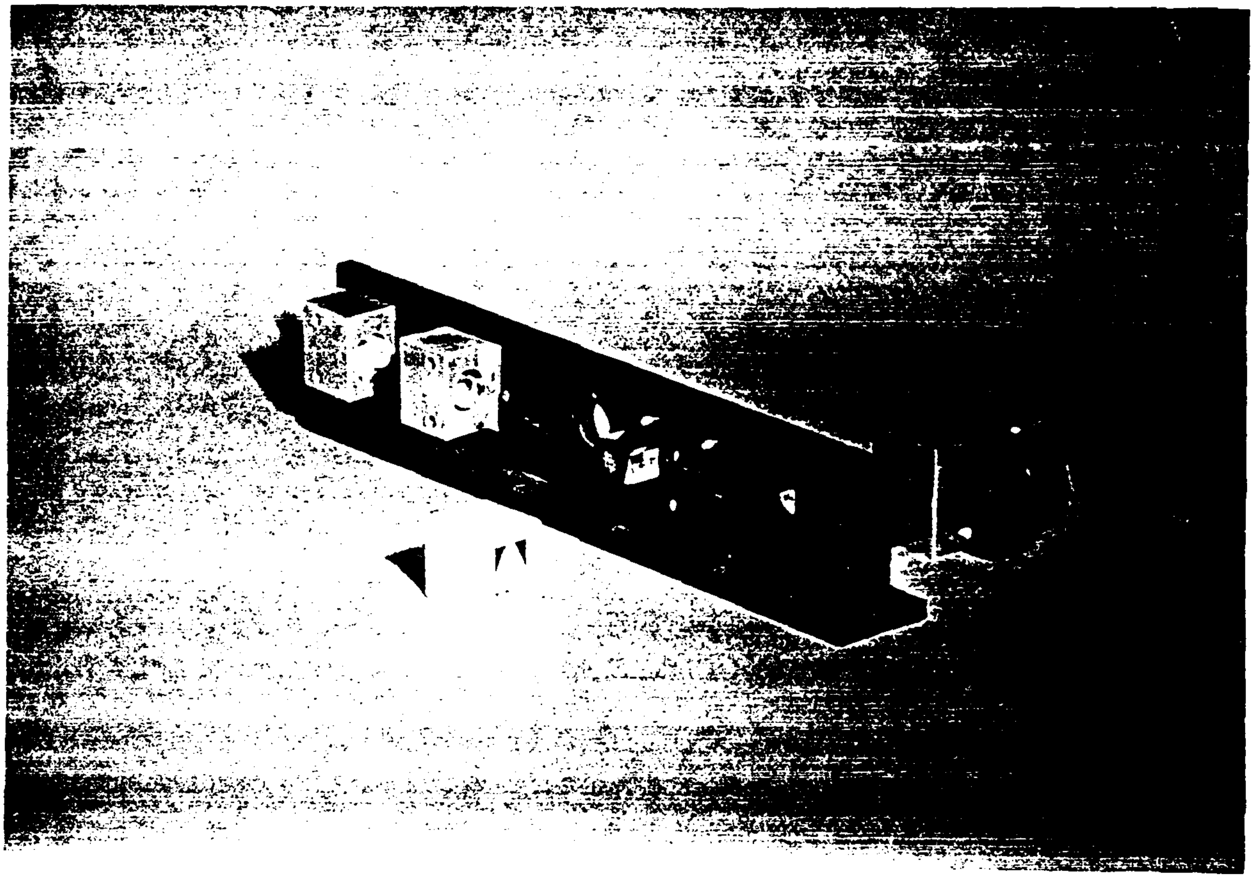


FIGURE 2-5: A PHOTOGRAPH OF TRANSCEIVER OPTO-MECHANICAL ASSEMBLY

2.3 DOPPLER RECEIVER ELECTRONICS

A block diagram of the receiver electronics is shown in Figure 2-6A below with a frequency translator section providing a wide range of center frequency settings for the FM discriminator.

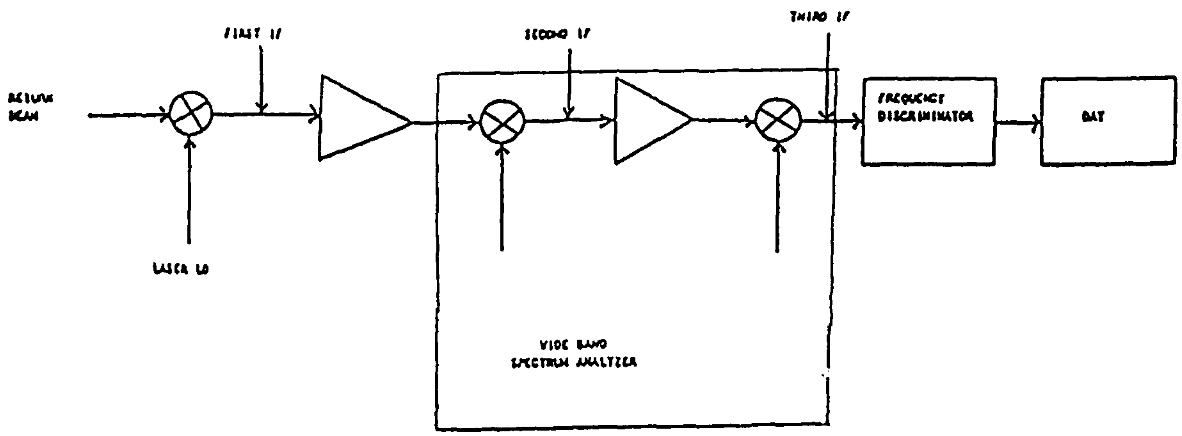


FIGURE 2-6A: BLOCK DIAGRAM OF THE RECEIVER ELECTRONICS

The breadboard frequency discriminator assembled for this program for Doppler sensitivity evaluation is based upon a design completed by ATC on other contract. The schematic for the FM discriminator portion is shown in Figure 2-6B has a maximum sensitivity of 10 volts/10 MHz that will be used in the homodyne receiver Doppler processor. The design was modified to meet the chosen third IF frequency at 21.4 MHz for the Hewlett Packard spectrum analyzer.

A digital/audio tape (DAT) recorder will provide high performance data acquisition for a Phase I LADAR. The 20 kHz audio bandwidth (>40 kHz A/D) and 14 bits of low noise, wide dynamic range could be used to record the output of a velocity discriminator directly, providing a 20 kHz slew rate with wide response to small Doppler changes and provide a means of accurate post experiment digital analysis.

A photograph of the receiver electronics is provided in Figure 2-7.

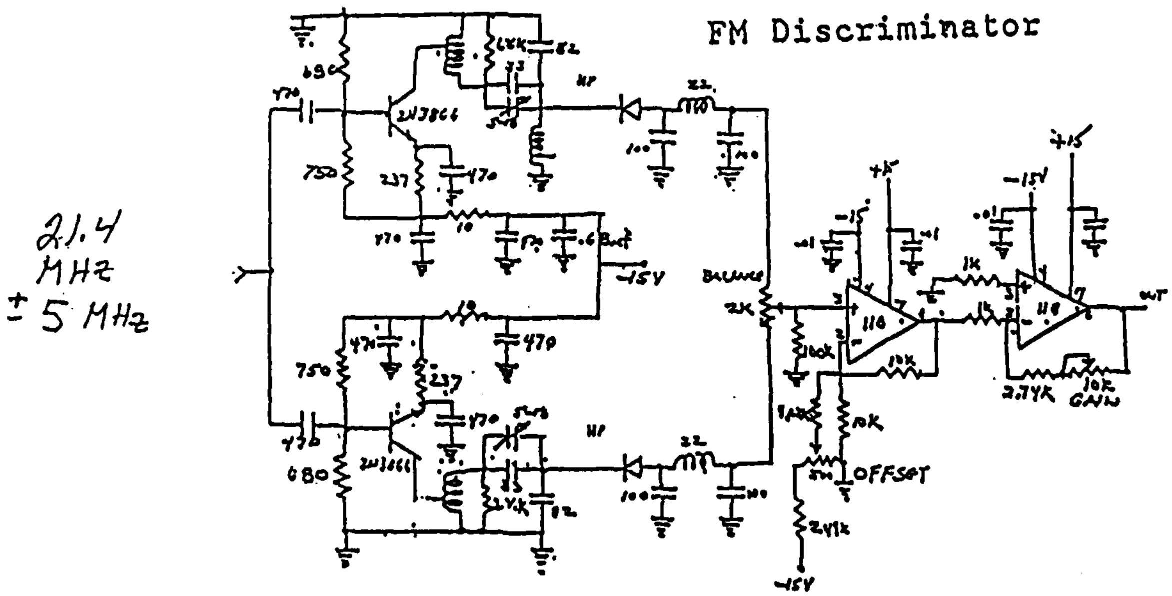


FIGURE 2-6B: DOPPLER RECEIVER ELECTRONICS SCHEMATIC

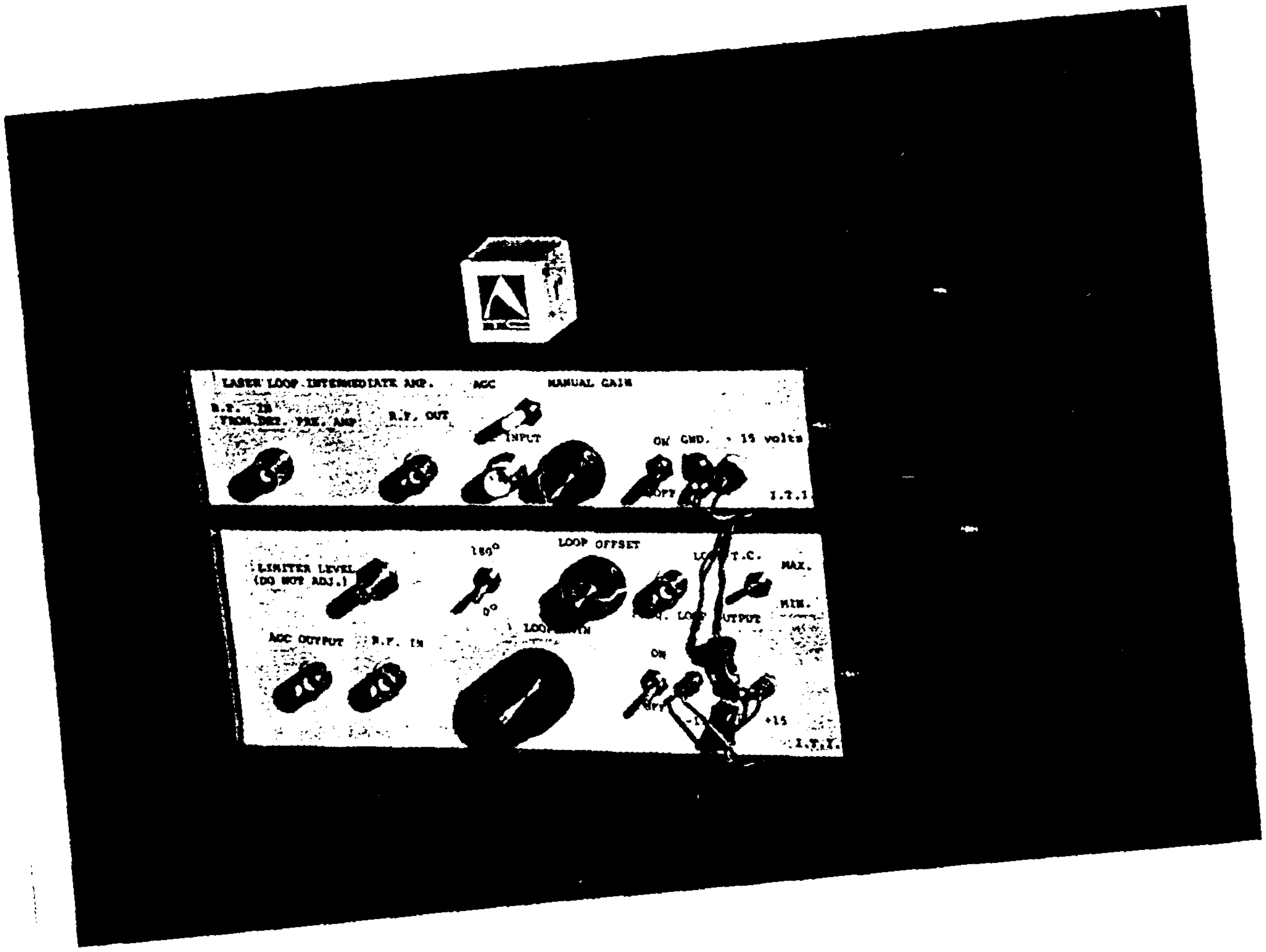


FIGURE 2-7: A PHOTOGRAPH OF RECEIVER ELECTRONICS

3.0 EXPERIMENTAL

The homodyne LADAR experiments against rotating conical target to gather Doppler data are not conducted so far. But the individual components were tested separately during the reporting period, some of the data collected is presented in this section.

3.1 EXPERIMENTAL SET UP AND RESULTS

A photograph of laser set up is provided in Figure 3-1. The single frequency Nd:YAG ring laser was enclosed in a transparent plastic is seen mounted on left side of the table. The pump diode laser was driven using a regulated DC power supply seen on right side. The pump diode laser current was monitored using a Beckman digital multimeter model 310B. The pump diode laser was mounted on a plate which was cooled by circulating refrigerated water at 20 degrees centigrade. The Burleigh variable power supply model P2-62 was used for the PZT. The ring laser output was monitored using Scientech model 373 power monitor (not shown in the photograph).

The input versus output characteristics of this unidirectional, single frequency, Nd:YAG ring laser is shown in Figure 3-2. Although, the collected shows that using this 200 mW at 808 nm pump diode laser provides single frequency Nd:YAG output of over 35 mW at 1064 nm, in order to obtain long life for the pump diode laser, the diode is operated only at its 50 percent rated output (100 mW) for continuous operation.

The single frequency Nd:YAG ring laser was delivered to ATC for the purpose of integration into the laser Doppler radar system and tests. The system assembled is shown in a photograph provided in Figure 3-3.

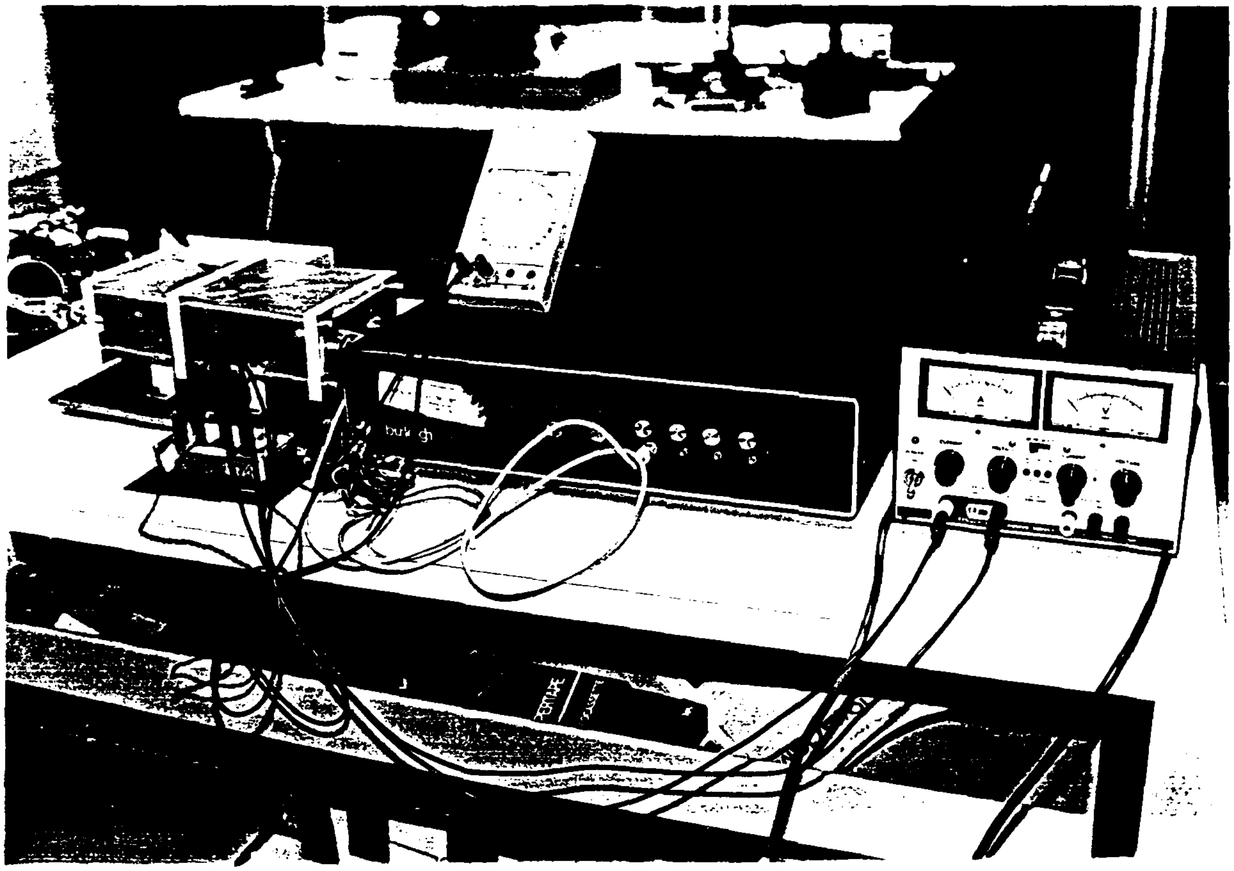


FIGURE 3-1: A PHOTOGRAPH OF LASER SET UP

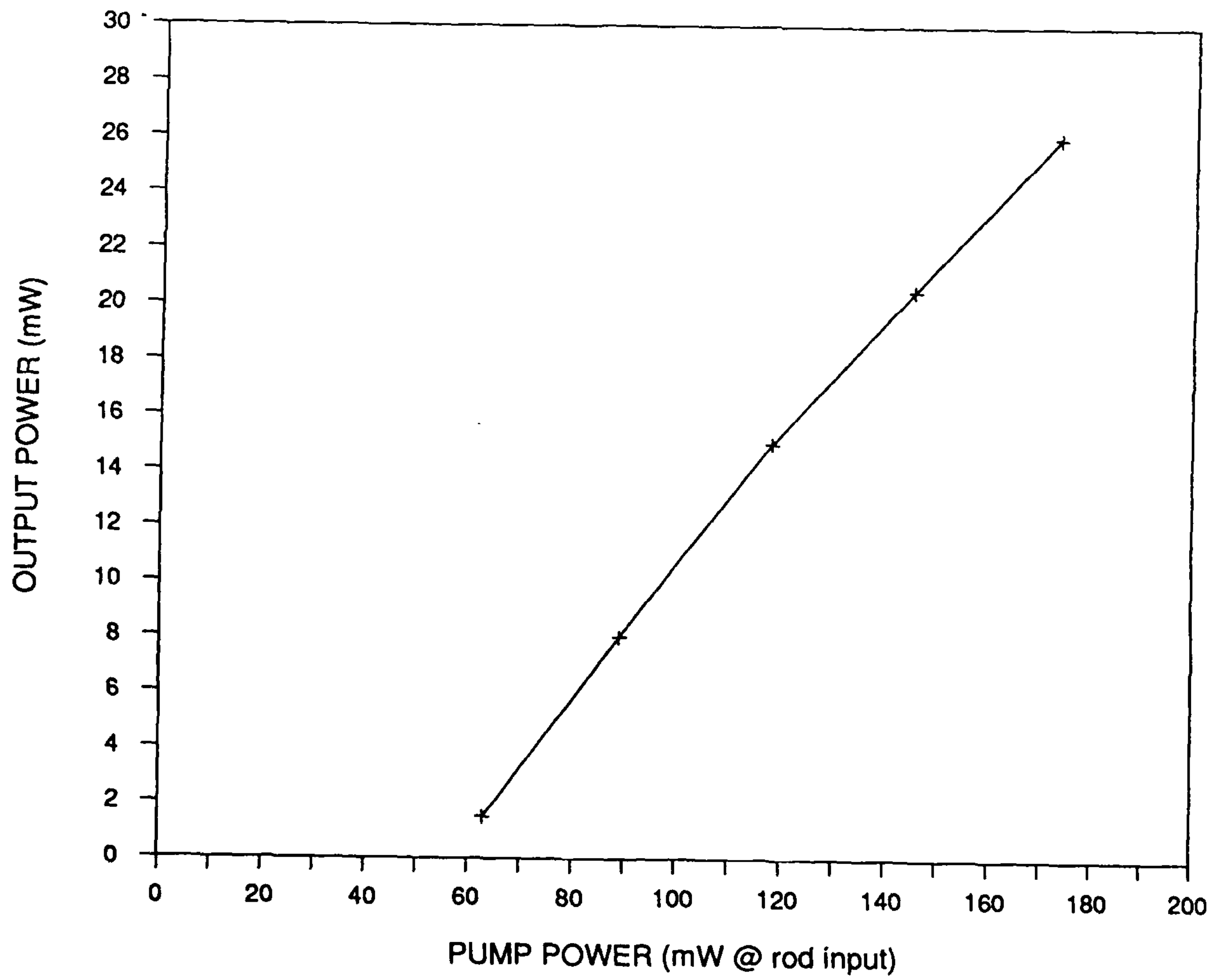


FIGURE 3-2: SINGLE FREQUENCY Nd:YAG RING LASER CHARACTERISTICS

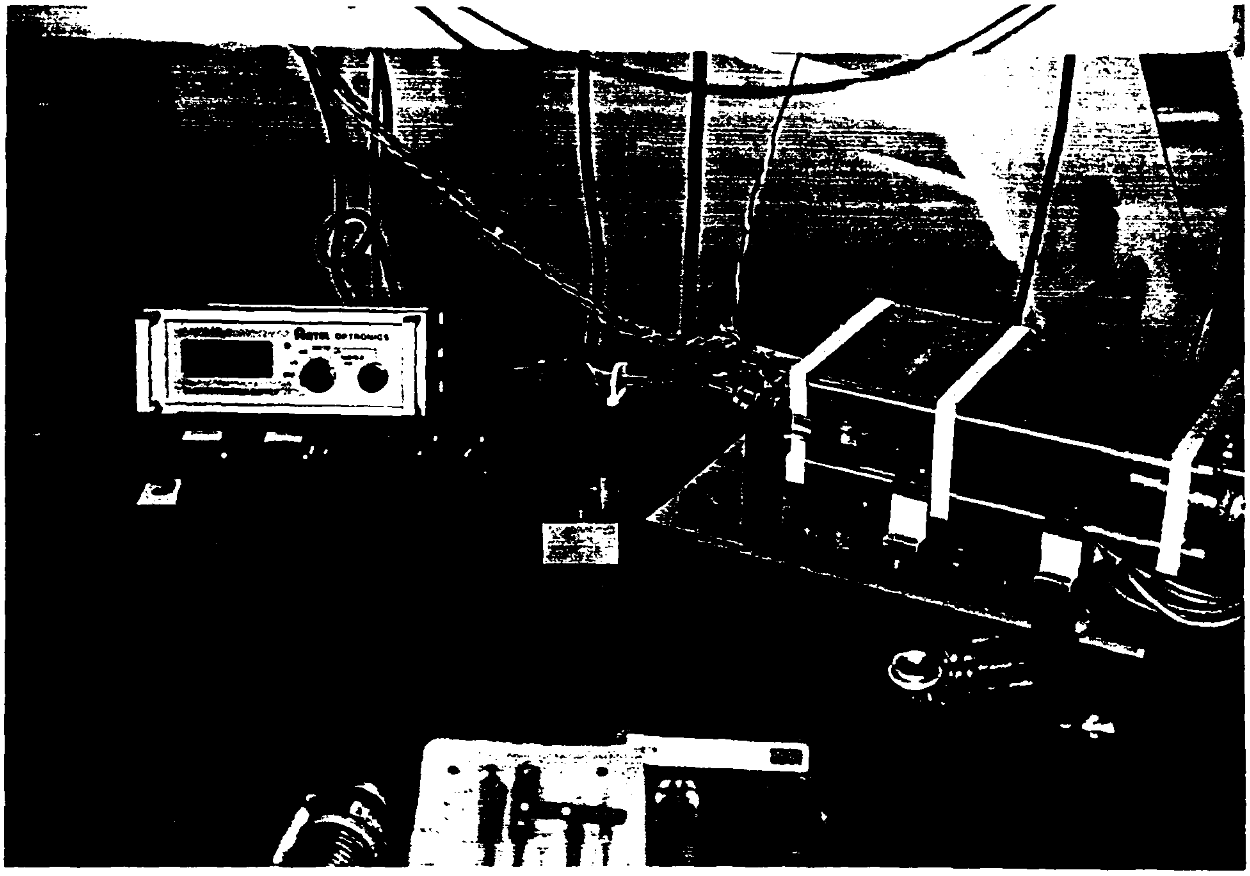


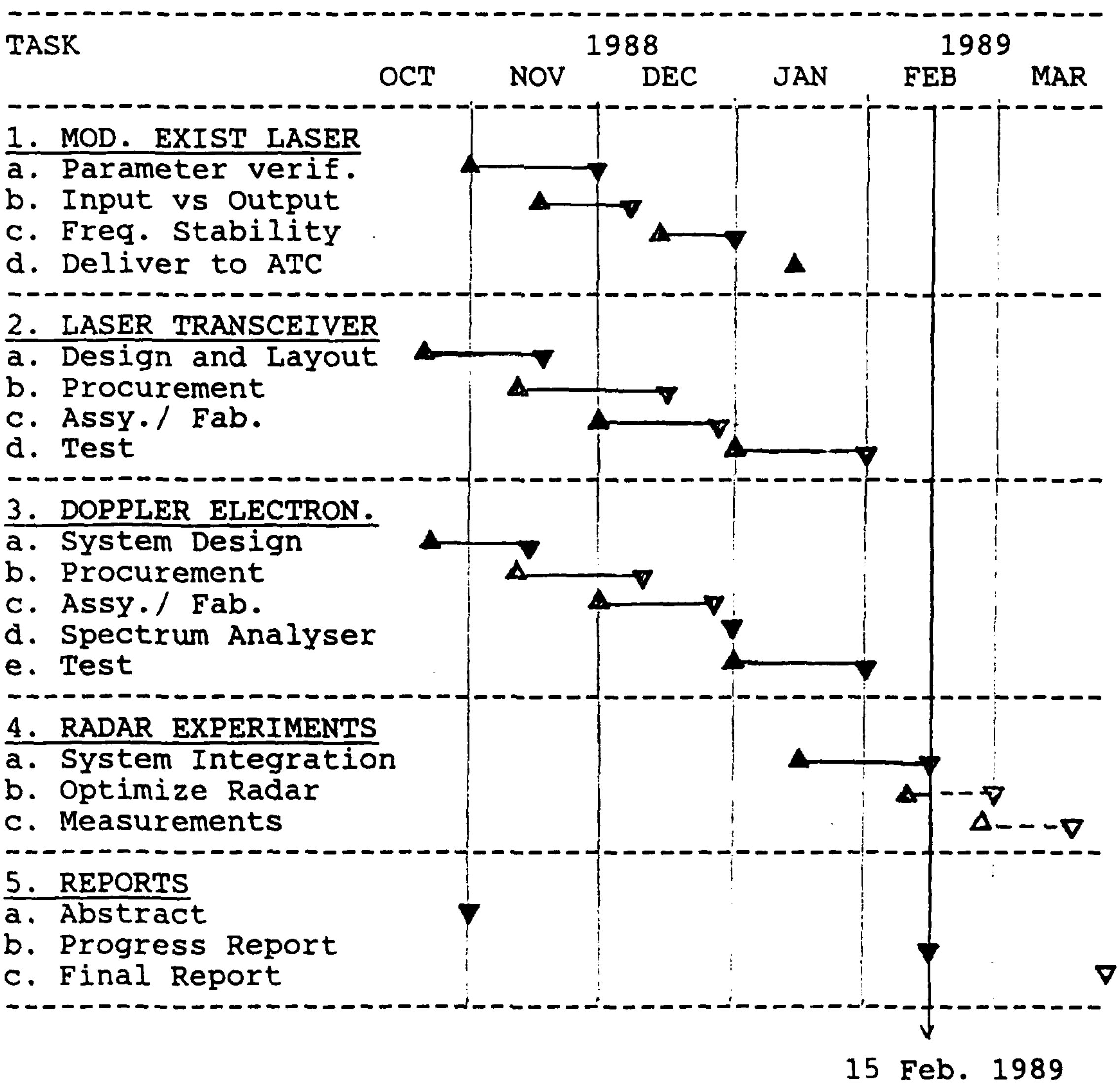
FIGURE 3-3: A PHOTOGRAPH OF HOMODYNE LADAR SET UP

3.2 SCHEDULE

The schedule for the one micron laser Doppler radar is shown in Table I below.

TABLE I

ONE MICRON LASER DOPPLER RADAR PROGRAM SCHEDULE



4.0 CONCLUSIONS

The following conclusions can be drawn based on the work performed on the contract so far:

1) A breadboard diode pumped Nd:YAG laser was assembled and tested. This single frequency laser provide upto 25 mW of CW output power. The laser beam can be divided using a beamsplitter for local oscillator and transmitter use.

2) A LADAR transceiver breadboard was designed, fabricated, and assembled. This opto-mechanical subassembly can be used in an homodyne mode of operation with the laser.

3) Doppler receiver electronics was designed, fabricated, and assembled. This component can be used with laboratory Doppler targets to collect data and characterize the system.

5.0 REFERENCES

1. "Tunable Single Frequency Nd Lasers for Coherent LIDAR," Contract #N66001-88-C-0095, Naval Ocean System Center, San Diego, CA 92152-5000.

2. "Homodyne to Heterodyne Conversion by Use Transverse Mode Spacing," by E. Biselli, Proceedings 3rd Topical Meeting on Coherent Laser Radar, p. 82, (1985).

3. "High Power, High Frequency Neodymium Laser End Pumped by a Single Stripe Laser Diode," by W. J. Skriac and H. P. Kortz, Paper EL1.2, 1988 LEOS Annual Meeting, Santa Clara, CA.

4. Spectra-Physics Fiber Coupled Series Diode Pumped Laser System, 7200 Model Series, Spectra-Physics, Inc., Mountain View, CA 94039.

5. "Efficient, Frequency-Stable Laser Diode Pumped Nd:YAG Laser," by B. Zhou, T. J. Kane, G. J. Dixon, and R. L. Byer, Opt. Lett., Vol. 10, p. 62, (1985).

6. "Efficient Laser Diode Side Pumped Neodymium Glass Slab Laser," by F. Hanson, and G. Imthurn, IEEE J. Quantum Electron., Vol. 10, p. 1811, (1988).

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